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United States Department of Agriculture

Forest Service

Correlation of the USDA Forest Service Drop Size Distribution Data Base

Forest Pest Management

Davis, CA

FPM 92-7
June 1992

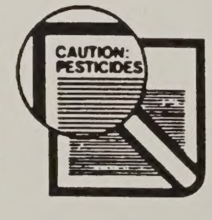
Pesticides used improperly can be injurious to human beings, animals, and plants. Follow the directions and heed all precautions on labels. Store pesticides in original containers under lock and key—out of the reach of children and animals—and away from food and feed.

Apply pesticides so that they do not endanger humans, livestock, crops, beneficial insects, fish, and wildlife. Do not apply pesticides where there is danger of drift when honey bees or other pollinating insects are visiting plants, or in ways that may contaminate water or leave illegal residues.

Avoid prolonged inhalation of pesticide sprays or dusts; wear protective clothing and equipment, if specified on the label.

If your hands become contaminated with a pesticide, do not eat or drink until you have washed. In case a pesticide is swallowed or gets in the eyes, follow the first aid treatment given on the label, and get prompt medical attention. If a pesticide is spilled on your skin or clothing, remove clothing immediately and wash skin thoroughly.

NOTE: Some States have restrictions on the use of certain pesticides. Check your State and local regulations. Also, because registrations of pesticides are under constant review by the U.S Environmental Protection Agency, consult your local forest pathologist, county agriculture agent, or State extension specialist to be sure the intended use is still registered.



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June 1992

CORRELATION OF THE USDA FOREST SERVICE DROP SIZE DISTRIBUTION DATA BASE

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Summary

Over the last several years the USDA Forest Service, and other government agencies and private companies, have contracted for wind tunnel tests to determine drop size distributions of spray material atomized by nozzles. These test results have been assembled into a data base presently containing 243 entries. Nearly all spray materials and nozzle types used by the USDA Forest Service are represented. Examination of some of this data indicates that spray drop size distributions may be correlated with each other in several simple ways, for example, but that variance in the distributions dictate the continued need for wind tunnel tests.

Introduction

The drop size distribution of spray material atomized by nozzles influences the magnitude of spray deposition, drift, evaporation and effectiveness. Several factors affecting the atomization process and the resulting spray distribution include nozzle type, hydraulic line pressure, flow rate and certain physical, chemical and biological properties of the formulation. The details of the resulting drop size distribution are important, especially to forest and agricultural applications, where specific levels of spray material must be deposited to achieve success. Environmental concerns over aerial spraying have escalated in the past several years, as has the cost of pesticides. It is becoming increasingly clear that the physical processes generating the spray distribution must be understood. The risk from drift is becoming too high, environmentally and economically.

In fact, what is driving the problem today is the requirement by the U. S. Environmental Protection Agency for drift data to support registration and re-registration of certain pesticides. To provide drift data the driftable part of the atomization must be known; however, wind tunnel tests are expensive and difficult to get people to do. Therefore, it becomes prudent to seek approaches that might reduce the need for extensive wind tunnel testing. One such approach is to develop a limited data base of wind tunnel tests, correlate these data, and then use them to extend predictions to conditions not tested.

Under the direction of the USDA Forest Service, wind tunnel tests of pesticides and simulant tank mixes have been conducted to:

1. Determine the atomization of tank mixes as influenced by hydraulic line pressure, flow rate, air velocity and shear across the atomizer, components including adjuvants (chemical, physical and biological) in the tank mix, viscosity, specific gravity, surface tension and other atmospheric conditions;

2. Evaluate the mixing and handling of the tank mix; and

3. Develop recommendations for field use of the tank mix.

Atomization results from these tests are then used in selecting the optimum combination of factors that have a high probability of meeting field project objectives. Wind tunnel facilities for testing pesticide sprays have been established and are maintained at University of California, Davis, California (where the pioneering work of Wes Yates and Norm Akesson occurred); Cranfield Institute of Technology, England; University of New Brunswick, Canada; USDA Agricultural Research Service, College Station, Texas; and New Mexico State University, Las Cruces, New Mexico.

Data Collection

Numerous researchers have investigated spray distributions that are essentially water-based (Yates, Cowden and Akesson [1]; Bouse, Carlton and Jank [2]), oil-based (Bouse and Carlton [3]) and generated from standard tank mixes (Picot, van Vliet and Payne [4]). Many other studies have been conducted, but their results are unpublished or held company proprietary. Generic results from these wind tunnel tests indicate the following:

1. Shear across hydraulic nozzles caused by nozzle orientation, and shear across the rotating basket cages of rotary nozzles caused by rotation, are major factors in break up that produces small drops;

2. Increase in surface tension increases drop size;

3. Viscosity is a minor influence on atomization;

4. Rotary atomizers can become overloaded with liquid volume, resulting in larger drop size atomization even when the rotation rate is held constant;

5. Most nozzles produce a large number of small drops (less than 56 micrometers in diameter); however, these drop sizes generally represent less than one percent of the total volume in the spray; and

6. Slight changes in some chemical, physical and biological properties of a tank mix can significantly alter the atomization.

It is this last observation that guarantees the continued need for wind tunnel tests. Although the development of atomization models (invoking similarity or dimensional analysis) is currently underway at U. C. Davis and Continuum Dynamics, Inc., these models are envisioned to enhance rather than replace the need to characterize tank mixes and spray systems. An examination of spray distributions in the above references ([1] to [4]) indicates that the behavior of spray distributions is strongly dependent upon variables that may not be easily quantified.

Spray drop size distributions are typically developed by using laser probes to scan the spray downstream of the nozzle. A flow-through wind tunnel provides an ambient air stream at the anticipated flight speed of the aircraft. A catcher downstream is usually used to capture the spray and prevent its release into the environment. The typical output from a single nozzle study at a single flight speed, and at other specified conditions depending on the nozzle type, is shown in Figure 1. Here the volume fraction is shown, although the same experiment will recover the number density as well. The typical gross features of interest are:

$D_{0.1}$ The diameter below which 10 percent of the spray material is found.

NMD Number Median Diameter: the diameter below which 50 percent of the spray drops are found.

SMD Sauter Mean Diameter: the diameter whose ratio of volume to surface area is the same as that of the entire spray.

VMD Volume Median Diameter: the diameter below which 50 percent of the spray volume is found.

$D_{0.9}$ The diameter below which 90 percent of the spray material is found.

The cumulative volume fraction CVF is generally shown (Figure 2), since it tends to smooth the distribution, de-emphasize details of the peak, and offer a result that clearly goes between zero and unity. Further operations on the cumulative volume fraction offer the prospects of representing its behavior mathematically. To this point previous researchers have dealt with limited data. Here, the extensive data base generated for the USDA Forest Service offers a new look at some old suggestions for collapsing data.

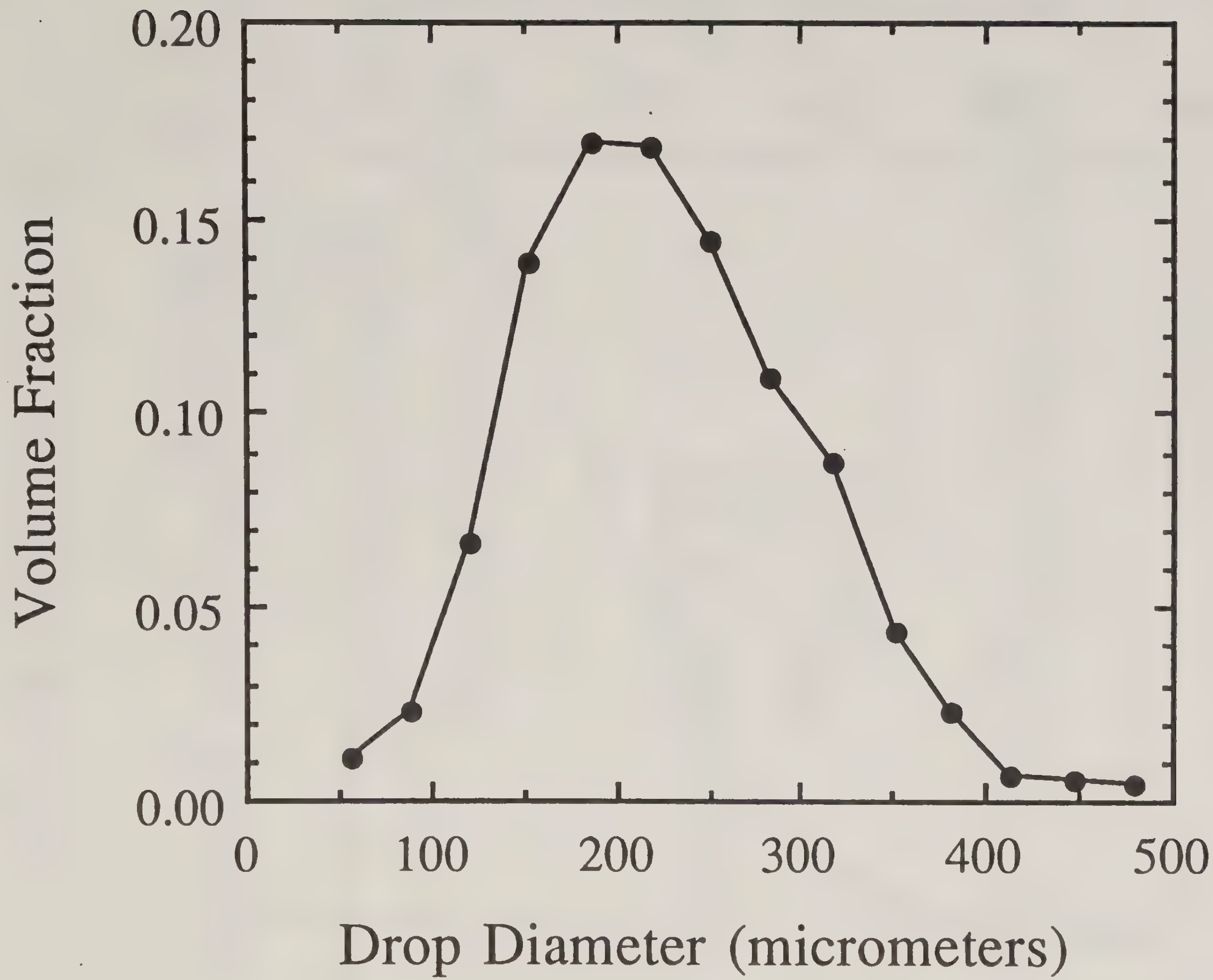

Figure 1. Spray drop size distribution volume fraction for an 8001 flat fan nozzle, spraying water and oriented zero degrees (parallel) to a 50 mph air stream. Pertinent drop diameters are $D_{0.1}$ = 121.39 µm ; NMD = 75.30 µm ; SMD = 178.46 µm ; VMD = 204.77 µm ; and $D_{0.9}$ = 310.56 µm.

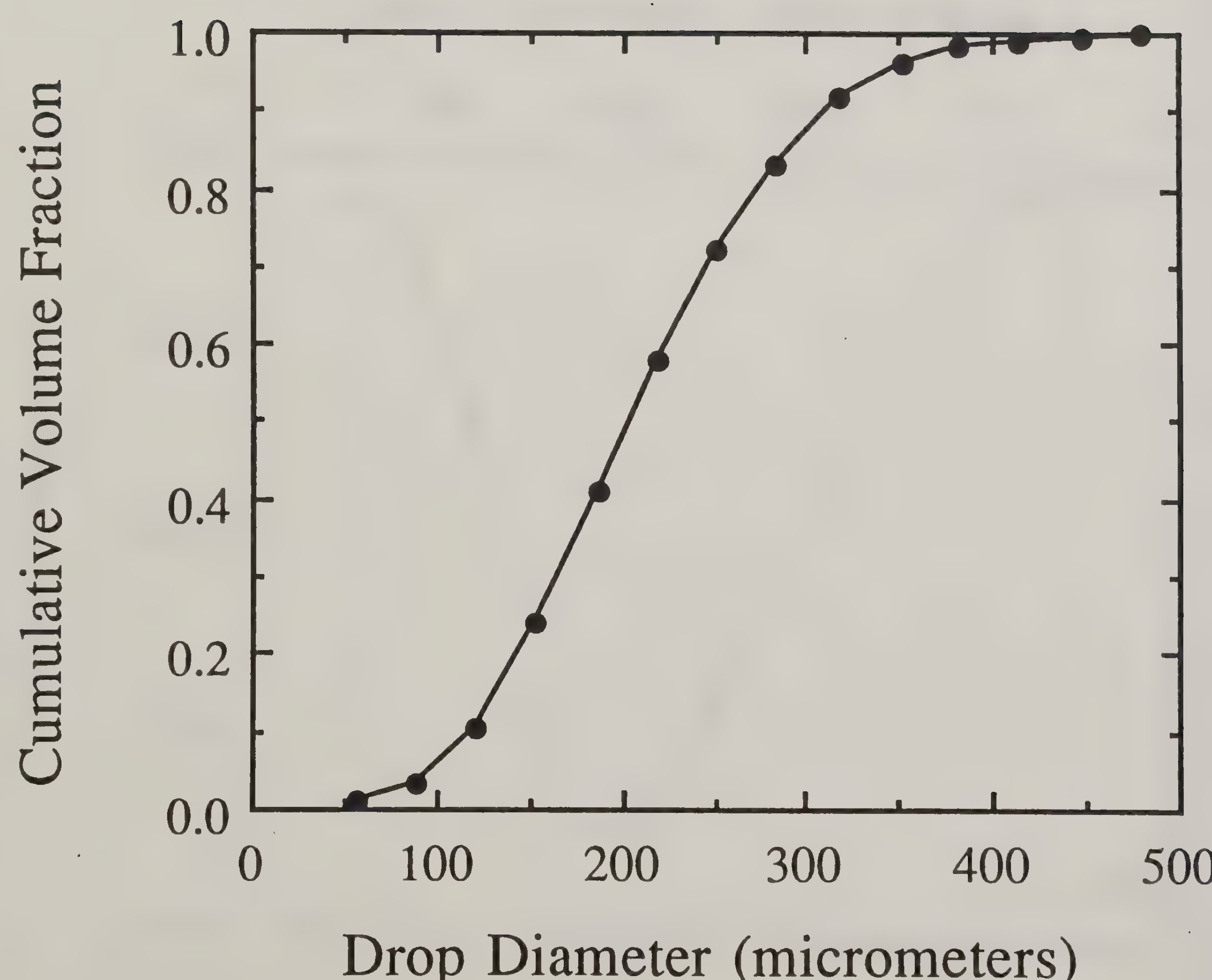

Figure 2. Cumulative volume fraction for the drop size distribution given in Figure 1.

Data Base Contents

Collected from published and unpublished reports, a spray drop size distribution data base has been compiled (Skyler and Barry [5]) and assembled into an interactive computer program (Teske [6]). This data base covers 40 spray materials and 27 nozzle types in 243 unique distributions (Tables 1 and 2). Most applications for these distributions include a variation in air speed, angle of the nozzle to the air stream (where applicable) or hydraulic line pressure or atomizer rotation rate. Nearly all spray materials and nozzle types used by the USDA Forest Service are represented in the data base.

Table 1. Spray materials in the USDA Forest Service data base. Several of the materials are in their undiluted ("neat") formulation; most are mixed with water.

Aatrex	San 415 SC 32LV
Dipel 6L and 8L	TM Biocontrol
Esteron	Thuricide 32LV, 48LV and 64LV
Foray 48B	Velpar
Garlon	Water
Glycerine	Water with Manganese Sulfate
Gypchek	Water with Manganese Sulfate and Nalco Trol
Roundup	Water with Nalco Trol

Table 2. Nozzle types in the USDA Forest Service data base.

Flat fan:	8001, 8002, 8003, 8004, 8006, 8010, 8020
Hollow cone:	D2-23, D2-25, D2-45, D3-45, D4-45, D4-46, D8-45, D8-46, D10-45
Jet:	D8, D10
Raindrop:	RD-7, RD-10
Rotary:	Airbi, Beecomist, Micronair AU5000, Micronair AU7000, Spinner, Unimizer

Data Correlation

Trying to find a way to correlate spray drop size distributions, where numerous variables can influence the results, has attracted attention to areas beyond aerial spraying, and has generated numerous insights into the problem. Goering and Smith [7] summarize the various techniques that have been attempted to essentially curve fit the cumulative volume fraction CVF. They ended up suggesting the three-parameter technique of Mugele and Evans [8] (upper-limit function) that extends the standard logarithmic normal approach of Rosin and Rammler [9]. The most redeeming feature of the logarithmic normal representation is the expectation of a straight-line fit through the data plotted on these particular axes.

Lefebvre [10] offers reasons for finding a suitable mathematical representation for the cumulative volume fraction distribution:

1. Provide a satisfactory fit to the drop size data;

2. Allow extrapolation to drop sizes outside the range of measured values;

3. Permit easy calculation of mean and representative drop diameters and other parameters of interest;

4. Provide a means of consolidating large amounts of data; and

5. Furnish insight into the basic mechanisms involved in atomization.

and offers the insight that, at present, no one function is generally superior to another for representing drop size distribution. In fact, he suggests that the best reasons for selecting a specific function would be:

1. Mathematical simplicity;

2. Ease of manipulation in computations; and

3. Consistent with the physical phenomena involved.

Logarithmic Normal

The most widely used expression for displaying drop size distribution is the Rosin-Rammler logarithmic normal representation:

$$1 - CVF = \exp[-(D_i / X)^q] \qquad (1)$$

where X and q are constants, and D_i is drop diameter. If the distribution displayed in Figure 1 is curve fit by least squares with Eq. 1, the results obtained are shown in Figure 3. In this instance the slope q equals 0.321 .

Upper-Limit

A more complicated technique is the Mugele-Evans upper-limit function, requiring the determination of three constants correlating drop size distribution to an error function behavior. Goering and Smith [7] give approximate formula for generating these three parameters:

$$D_m = \frac{VMD\,(D_{0.1} + D_{0.9}) - 2\,D_{0.1}\,D_{0.9}}{VMD - D_{0.1}\,D_{0.9} / VMD} \tag{2}$$

$$A = \frac{D_m - VMD}{VMD} \tag{3}$$

$$\delta = \frac{0.394}{\log_{10}\left(\frac{A\,D_{0.9}}{D_m - D_{0.9}}\right)} \tag{4}$$

to give

$$CVF = 0.5\,(1 + \mathrm{erf}\,(\delta z)) \tag{5}$$

$$z = \log\left(\frac{A\,D_i}{D_m - D_i}\right) \tag{6}$$

and erf is the commonly defined error function. The correlation is displayed in Figure 4.

Normal Probability

One technique that shows particular promise was developed by Simmons [11] from an idea he attributed to Tate and Marshall [12]. In this technique the CVF is plotted on a normal probability distribution scale as a function of the square root of the drop diameter. The results were generally so startling that the authors felt compelled to dismiss divine intervention and intimate that the correlation was purely empirical and should not be used as a basis for theoretical interpretation.

For the types of nozzles tested in wind tunnels by the USDA Forest Service, this "root/normal" approach is even more appealing if the drop diameters D_i are normalized by their volume median diameter VMD, as suggested by D. Esterly (private communication). Application of the root/normal approach to the same drop size distribution gives the result shown in Figure 5, where use has been made of Equations 26.2.18 and 26.2.23 in Abramowitz and Stegun [13] to extract the normal probability distribution function and its inverse.

A simple least squares fit through this data gives the solid line shown in Figure 5, defined by the equation $y = 0.9866 + 0.1774\,x$, where x is the inverse of the normal probability distribution function ($x = 0$ is a probability of 0.5) and $y = \sqrt{D_i / VMD}$. The corresponding volume fraction curve is shown by the data and solid curve in Figure 6. These results generate a number of observations:

1. Because of our normalizing procedure, we would have anticipated that at $x = 0$ we would find $y = 1$, since the midpoint of the probability curve should recover the VMD. Our first guess for VMD was the value suggested by the experiment, which probably used a linear interpolation technique between two drop diameters, and may be in error by several micrometers.

2. The low end of the distribution contains some uncertainty. The wind tunnel technique generally did not resolve drop diameters below 32 micrometers, which suggests that the base volume fraction is not 0 but should be some (small) positive value. However, in this case the anticipation is that the volume lost is minimal.

3. The high end of the distribution also contains some uncertainty. According to W. Yates and N. Akesson (private communication), the last entries in several of their distributions could have been the result of drips formed off the nozzle machinery, and not a clear product of atomization. These large drops could, unfortunately, dramatically influence the VMD used to normalize results.

The least squares technique treats each data point equally, when in fact our concern is to maximize the common area agreement in Figure 6. Thus, the approach suggested to improve our agreement is two-fold:

1. We will require that the straight-line curve fit in Figure 5 goes through the $x = 0$ and $y = 1$ point.

2. We will then find the curve fit in Figure 5 that maximizes the common area in Figure 6.

The slope of the straight line and the effective VMD form a two-parameter family of variables determined by a consistent trial and error solution technique. With this technique we diminish the importance of data points on either end of the drop size distribution. Results for this approach are given by the dashed curves in the two figures, where the straight line is now $y = 1.0 + 0.1856\,x$ and the agreement in Figure 6 is significantly improved. Average common area coverage is 77.99 percent by least squares, and 86.87 percent by common area maximization. The VMD values change by an average of 5.44 micrometers.

The application of this technique to all entries in the drop size data base results in the two-parameter family of values shown in Figure 7. The improvement made by maximizing the area under the volume fraction curve is shown in Figure 8, where it is seen that in all cases the technique improves the correlation with data.

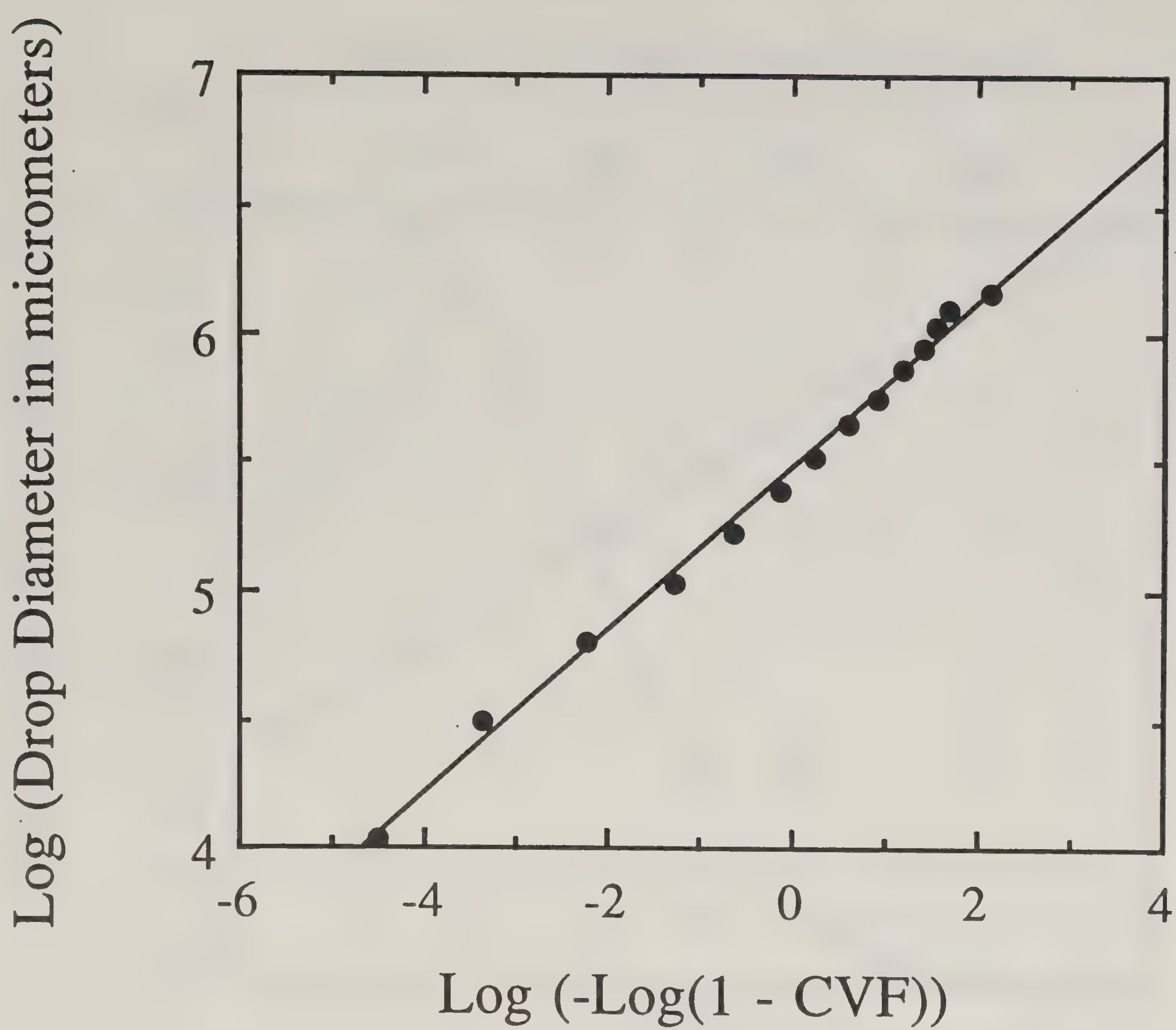

Figure 3. Logarithmic normal representation of the drop size distribution given in Figure 1. The slope of the straight-line fit in this coordinate space is 0.321 .

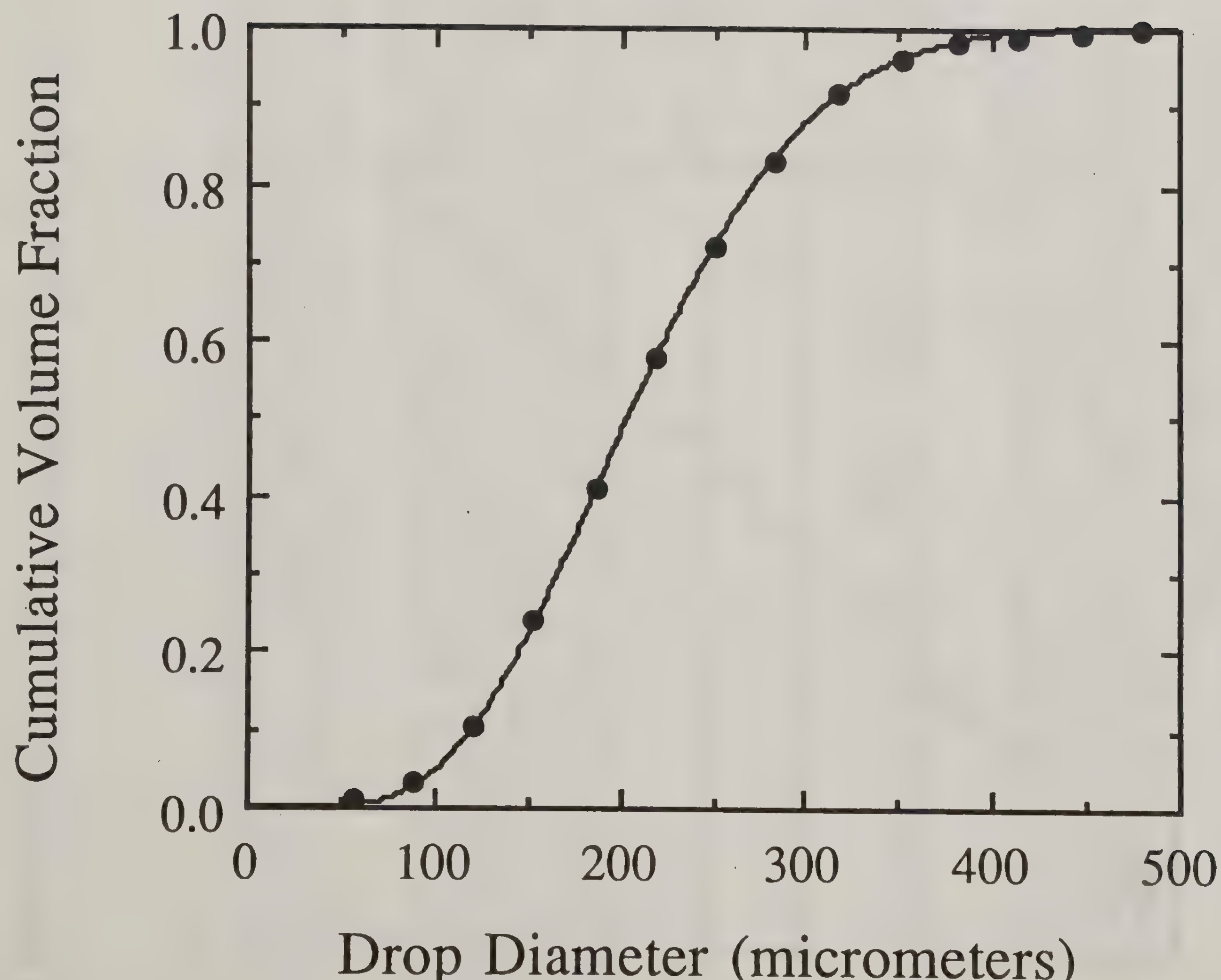

Figure 4. Upper-limit function representation of the drop size distribution given in Figure 1. The pertinent parameters are $D_m = 631.59$ µm ; $A = 2.084$; and $\delta = 1.294$.

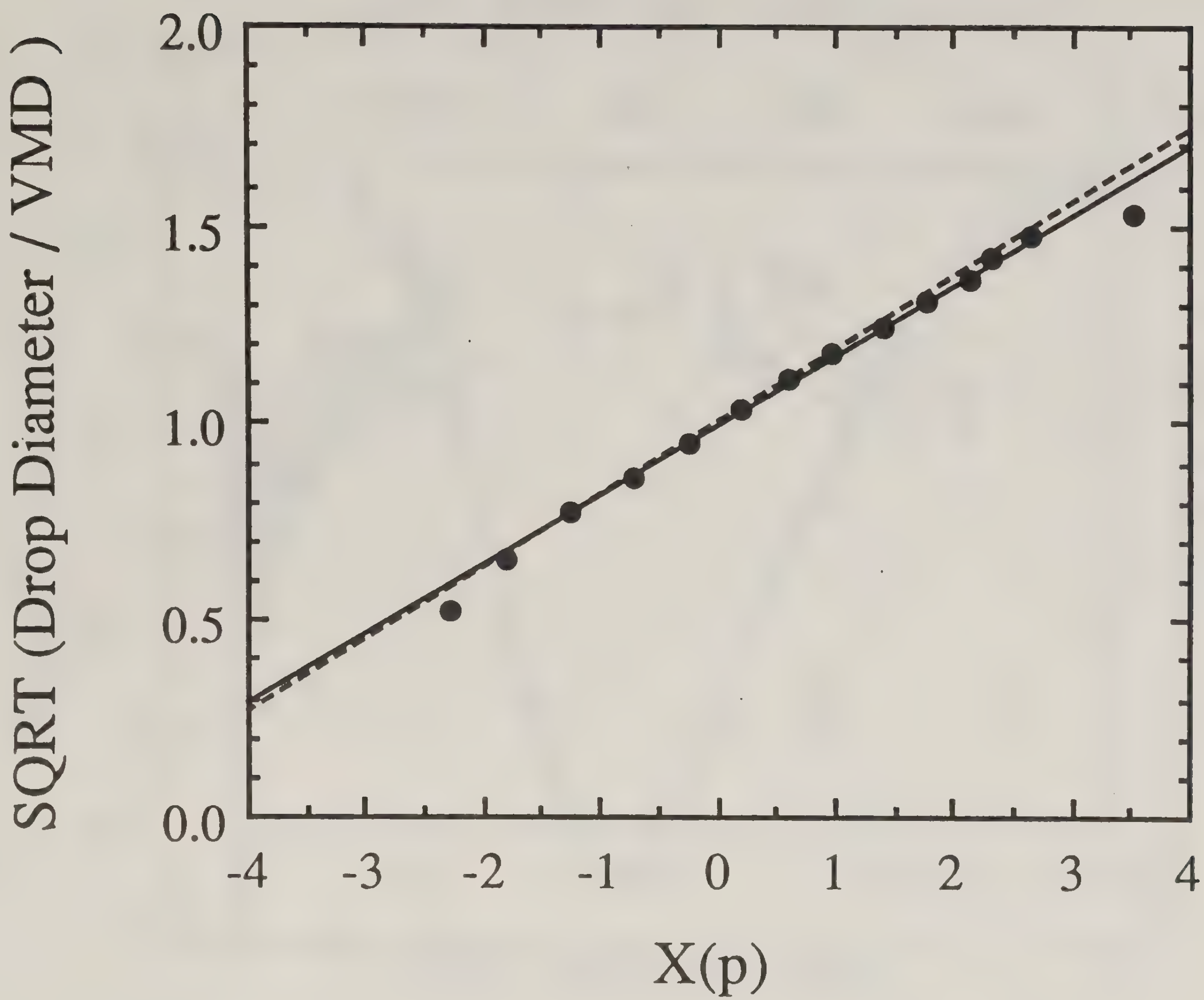

Figure 5. Normal probability representation of the drop size distribution given in Figure 1, plotted against the square root of the drop diameter. $X(p)$ is such that at $X(p) = 0$ the probability is 0.5 . The solid line is the least squares fit; the dashed line maximizes the common area in Figure 6.

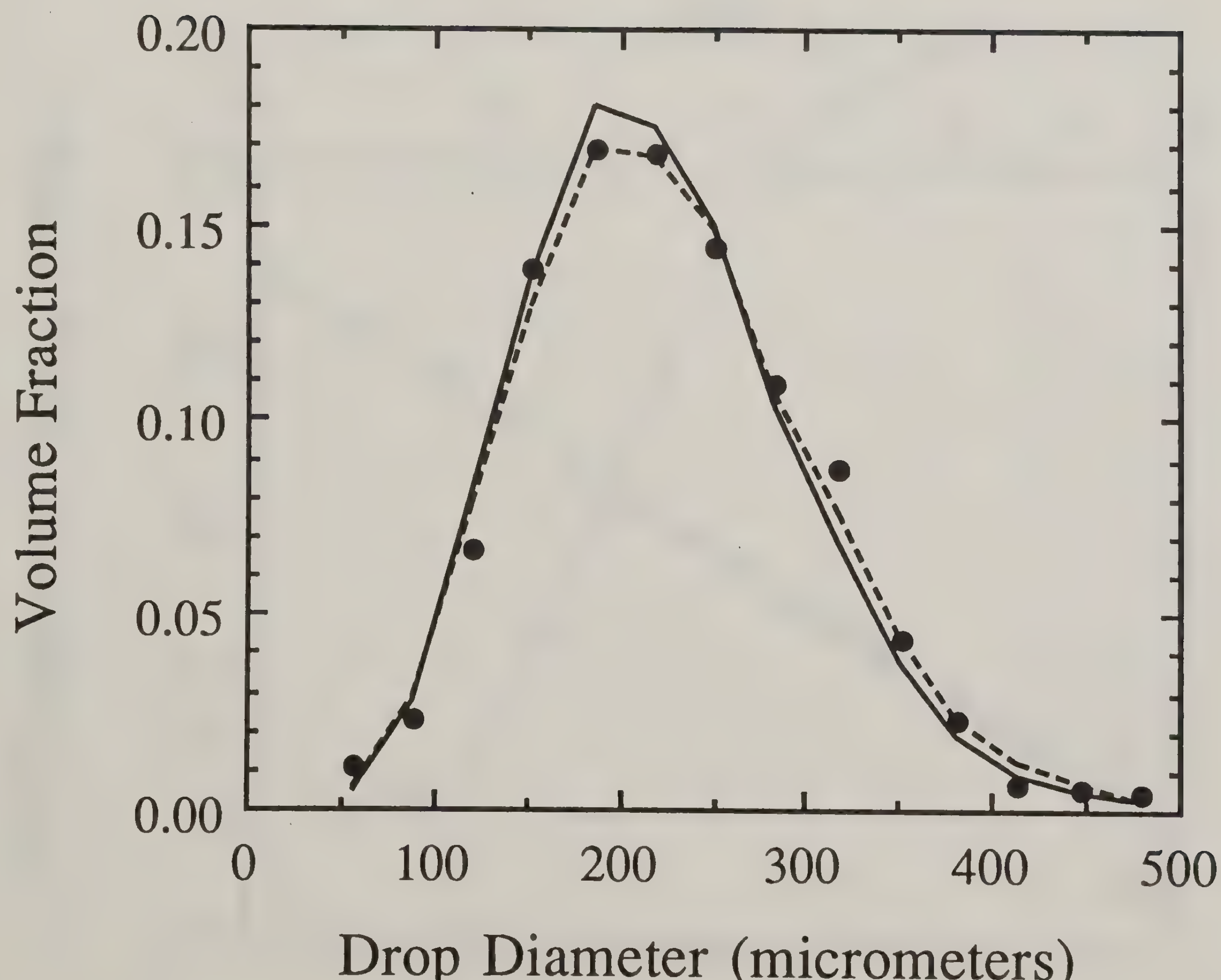

Figure 6. Corresponding drop size distribution by volume fraction for the curve fits from Figure 5.

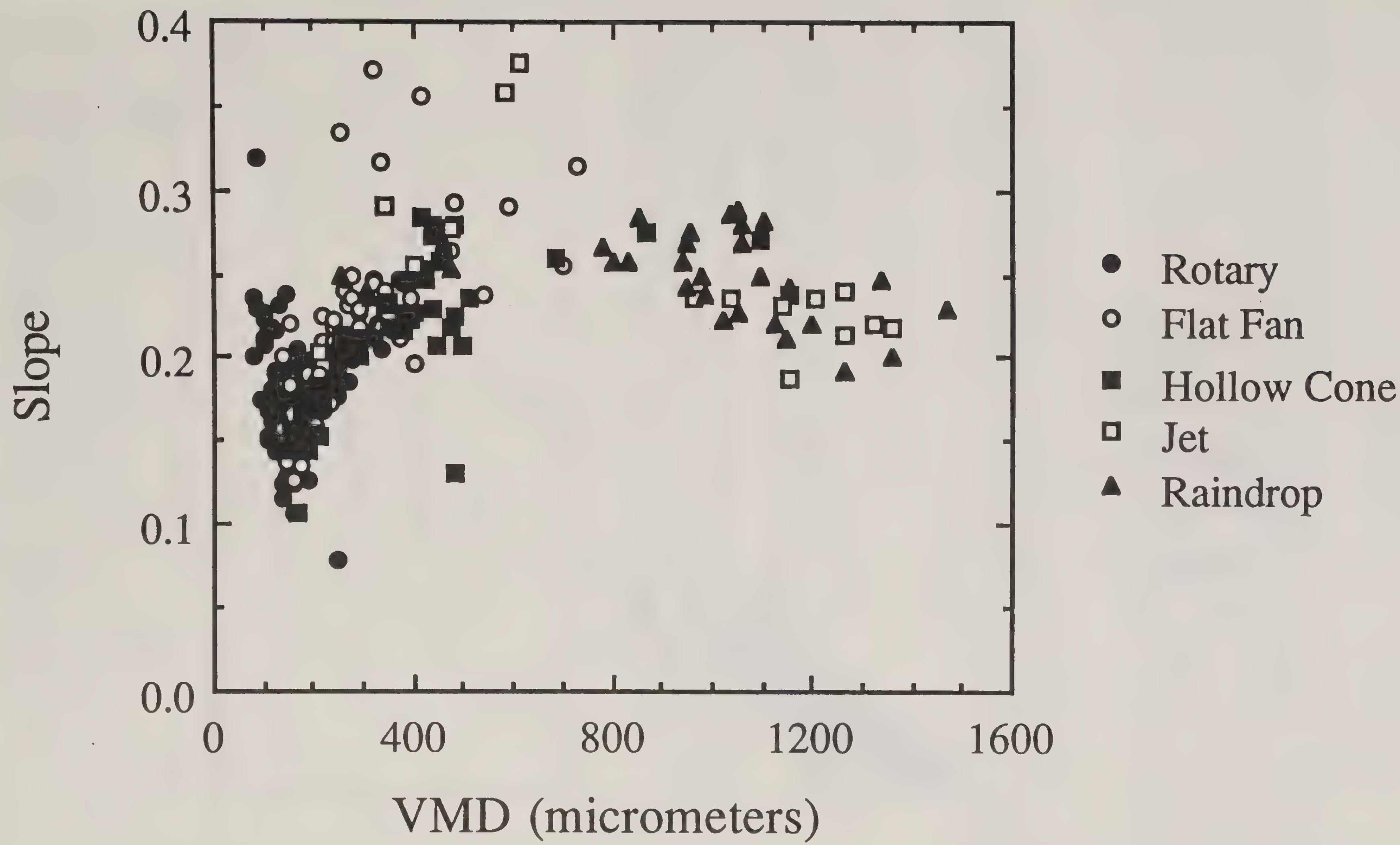

Figure 7. All drop size data correlated with the normal probability approach and reduced to VMD and Slope values typical of that shown in Figure 5.

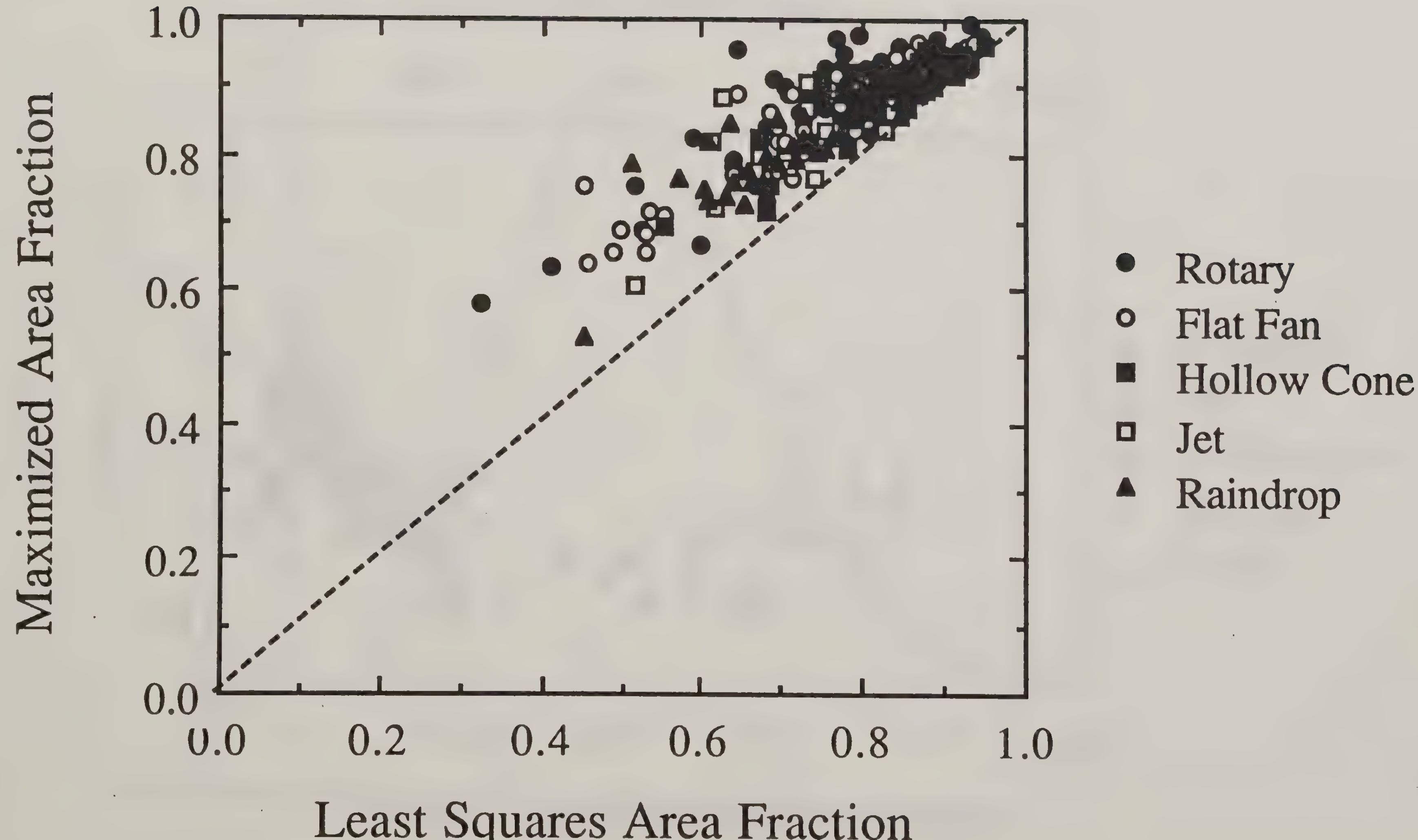

Figure 8. Improvement in area covered by the normal probability approach over the least squares technique.

Data Base Extension

With the data collapsed such that a two-parameter family of values (VMD and Slope) describe all drop size distributions in the data base, the question arises as to the use of these results in interpolating within the data base. Specifically, we wish to formulate the appropriate question that would be asked if the data were used advantageously: namely, if data were not available on a specific nozzle and material combination, how might the data base be used to infer the drop size distribution appropriate for that specific combination? Two additional questions are: how much data would be needed to infer this result; and, with what accuracy would the distribution be obtained?

To examine these questions as clearly as possible, we concentrate on a subset of the entire data base, specifically the rotary, flat fan, hollow cone and raindrop nozzle results for water for which multiple combinations have been examined. In this way correlation of the data might be possible. The pertinent two-parameter results are given in Table 3.

The suggested procedure is as follows:

1. For any real applications, several drop size distributions would share some common features with the spray combinations desired. These particular distributions are first identified for further manipulation.

2. The most straightforward use of these selected drop distribution would be to form a Taylor series expansion from each known VMD and Slope, to the unknown but desired values of VMD and Slope. This procedure may be developed symbolically by writing (for VMD as the example):

$$VMD_{new} = VMD_{old} + \frac{\partial VMD}{\partial U}\Delta U + \frac{\partial VMD}{\partial Q}\Delta Q + \frac{\partial VMD}{\partial \alpha}\Delta\alpha \tag{7}$$

   where

   $\Delta U = U_{new} - U_{old}$ = speed difference

   $\Delta Q = Q_{new} - Q_{old}$ = flow rate difference

   $\Delta\alpha = \alpha_{new} - \alpha_{old}$ = nozzle angle (or rotation rate) difference

   The expressions involving partial derivatives ($\partial VMD/\partial U$, $\partial VMD/\partial Q$ and $\partial VMD/\partial\alpha$) are called the influence coefficients.

3. Given several selected drop size distributions, we form a least squares solution procedure for the influence coefficients. This implies that we have selected at least as many data pairs as we have variations in speed, flow rate and nozzle angle (or rotation rate). Thus, if there are only two drop size distributions with common conditions to the one we wish to find solution for, only one variation (such as in speed) is permitted; otherwise

the problem will be underdetermined. Hopefully, more data shares common conditions with the results we seek, the problem becomes overdetermined, and we use the least squares technique to solve for the three influence coefficients.

In this configuration we further write:

$$\Delta R = VMD_{new} - VMD_{old} \tag{8}$$

$$A = \partial VMD/\partial U \qquad B = \partial VMD/\partial Q \qquad C = \partial VMD/\partial \alpha \tag{9}$$

and form the least squares error function representation:

$$E = \sum [\ \Delta R - A\,\Delta U - B\,\Delta Q - C\,\Delta\alpha\ ]^2 \tag{10}$$

Minimization of this error leads to three equations in the three unknowns A, B and C. This procedure is repeated for the Slope as well.

4. With the determined values of the influence coefficients, the desired drop size distribution is reconstructed.

In theory this procedure should be a viable one; in practice the large swings in VMD and Slope that represent the drop size distribution data base, especially in those cases where the original wind tunnel data shows a bimodal shape, make extrapolation from the known distributions a tentative undertaking. Unless the desired conditions are "close" to a known drop size distribution, significant differences generally occur for the predicted results. To illustrate: the data pairs given in Table 3 have been used to predict themselves (one data point in turn is predicted by all other data points, then compared to its actual value). The resulting summary curves, Figures 9 and 10 for VMD and Slope respectively, are constructed. These curves show that relative standard deviations generated by implementing this technique as a function of how far the selected data is from the desired and predicted base values of VMD and Slope. Overall, these results show that we are able to predict the VMD to only within 20 percent of its actual value; and the Slope, to within ten percent or so. These results for VMD are an improvement over previous techniques (Picot, van Vliet and Payne 1989 correlated spray VMD to within 35 percent), but they still represent too strong a difference from the actual values. The resulting predicted drop size distribution would be too far removed from its actual slope to make support this approach viable.

The summaries given in Figures 9 and 10 should not detract from specific application of the approach using the data base. In these instances, the approach may be quite reliable. Thus, it seems prudent to implement the techniques into the DROPSIZE program (Teske 1990) and permit users to experiment with creating drop size distributions not available from wind tunnel tests. This approach would be a step in the right direction toward reducing the number of wind tunnel tests needed. Since the technique works when the known data is close to the desired conditions, wind tunnel tests will only be needed for the limiting field application parameters. Then, during the field trials, any small variation from these conditions (such as a change in aircraft speed) can be correlated with confidence to generate the representative drop size distribution.

Table 3: Two-parameter family of results for water discharge in the drop size distribution data base.

Rotary	Flow Rate (gal/min)	Speed (mph)	Rotation (rpm)	VMD (µm)	Slope
AU5000	0.6	50	3750	251.90	0.0781
	3.0	50	4100	291.20	0.2265
	3.0	100	4200	206.05	0.1664
	3.79	100	7000	161.67	0.1236
	3.0	100	8000	118.37	0.1746
	0.6	100	9100	111.18	0.1520
	3.0	130	10850	79.26	0.2351
	2.55	135	11000	110.94	0.2166
	0.6	130	11700	80.93	0.2001

Raindrop	Flow Rate (gal/min)	Speed (mph)	Angle (deg)	VMD (µm)	Slope
RD-7	0.84	50	0	1051.63	0.2266
	0.84	100	0	476.22	0.2537
	0.84	150	0	242.29	0.2048
	0.84	50	90	778.44	0.2671
	0.84	100	90	306.82	0.2403
	0.84	150	90	184.28	0.1771
RD-10	1.53	50	0	1035.67	0.2867
	1.53	100	0	457.08	0.2693
	1.53	150	0	257.54	0.2502
	1.53	50	90	857.98	0.2852
	1.53	100	90	313.07	0.2354
	1.53	150	90	185.72	0.1738

Table 3: Two-parameter family of results for water discharge in the drop size distribution data base (continued).

Flat Fan	Flow Rate (gal/min)	Speed (mph)	Angle (deg)	VMD (µm)	Slope
8001	0.1	50	0	204.09	0.1856
	0.1	100	0	210.21	0.1911
	0.1	150	0	195.95	0.1780
	0.1	50	90	232.22	0.1797
	0.1	100	90	184.98	0.1613
	0.1	150	90	140.04	0.1573
	0.1	50	135	217.09	0.1844
	0.1	100	135	181.90	0.1577
	0.1	150	135	145.15	0.1367
8004	0.4	50	0	358.40	0.2158
	0.4	100	0	333.05	0.2190
	0.4	150	0	257.22	0.2069
	0.4	50	90	327.68	0.2211
	0.4	100	90	237.68	0.2100
	0.4	150	90	174.01	0.1420
	0.4	50	135	293.56	0.2183
	0.4	100	135	204.85	0.1600
	0.4	150	135	158.84	0.1278
8010	1.0	50	0	542.31	0.2389
	1.0	100	0	475.62	0.2643
	1.0	150	0	280.95	0.2490
	1.0	50	90	422.97	0.2527
	1.0	100	90	256.42	0.2083
	1.0	150	90	185.28	0.1502
	1.0	50	135	343.91	0.2396
	1.0	100	135	215.23	0.1785
	1.0	150	135	176.54	0.1347
8020	2.0	50	0	704.70	0.2549
	2.0	100	0	592.03	0.2908
	2.0	150	0	334.47	0.3172
	2.0	50	90	478.54	0.2928
	2.0	100	90	289.22	0.2303
	2.0	150	90	211.43	0.1729
	2.0	50	135	395.15	0.2352
	2.0	100	135	236.17	0.1862
	2.0	150	135	185.85	0.1486

Table 3: Two-parameter family of results for water discharge in the drop size distribution data base (continued).

Hollow Cone	Flow Rate (gal/min)	Speed (mph)	Angle (deg)	VMD (μm)	Slope
D2-23	0.1	50	0	207.64	0.1808
	0.1	100	0	186.97	0.1788
	0.1	150	0	171.47	0.1077
	0.1	50	90	198.64	0.1731
	0.1	100	90	193.41	0.1437
	0.1	150	90	154.37	0.1451
D2-25	0.16	50	0	218.38	0.1841
	0.16	100	0	200.60	0.1706
	0.16	150	0	187.33	0.1529
	0.16	50	90	212.91	0.1839
	0.16	100	90	199.31	0.1552
	0.16	150	90	156.17	0.1570
D4-45	0.36	50	0	291.46	0.2000
	0.36	100	0	252.99	0.2000
	0.36	150	0	211.80	0.1531
	0.36	50	90	263.45	0.2019
	0.36	100	90	221.55	0.1722
	0.36	150	90	171.77	0.1668
D4-46	0.56	50	0	437.88	0.2299
	0.56	100	0	350.42	0.2326
	0.56	150	0	266.59	0.2024
	0.56	50	90	343.99	0.2310
	0.56	100	90	249.00	0.1968
	0.56	150	90	174.23	0.1595
D8-45	0.84	50	0	378.88	0.2168
	0.84	100	0	320.95	0.2127
	0.84	150	0	236.82	0.1841
	0.84	50	90	347.48	0.2333
	0.84	100	90	254.53	0.2149
	0.84	150	90	185.57	0.1538
D8-46	1.84	50	0	507.86	0.2370
	1.84	100	0	437.41	0.2731
	1.84	150	0	261.51	0.2122
	1.84	50	90	451.33	0.2579
	1.84	100	90	302.39	0.2127
	1.84	150	90	191.62	0.1727

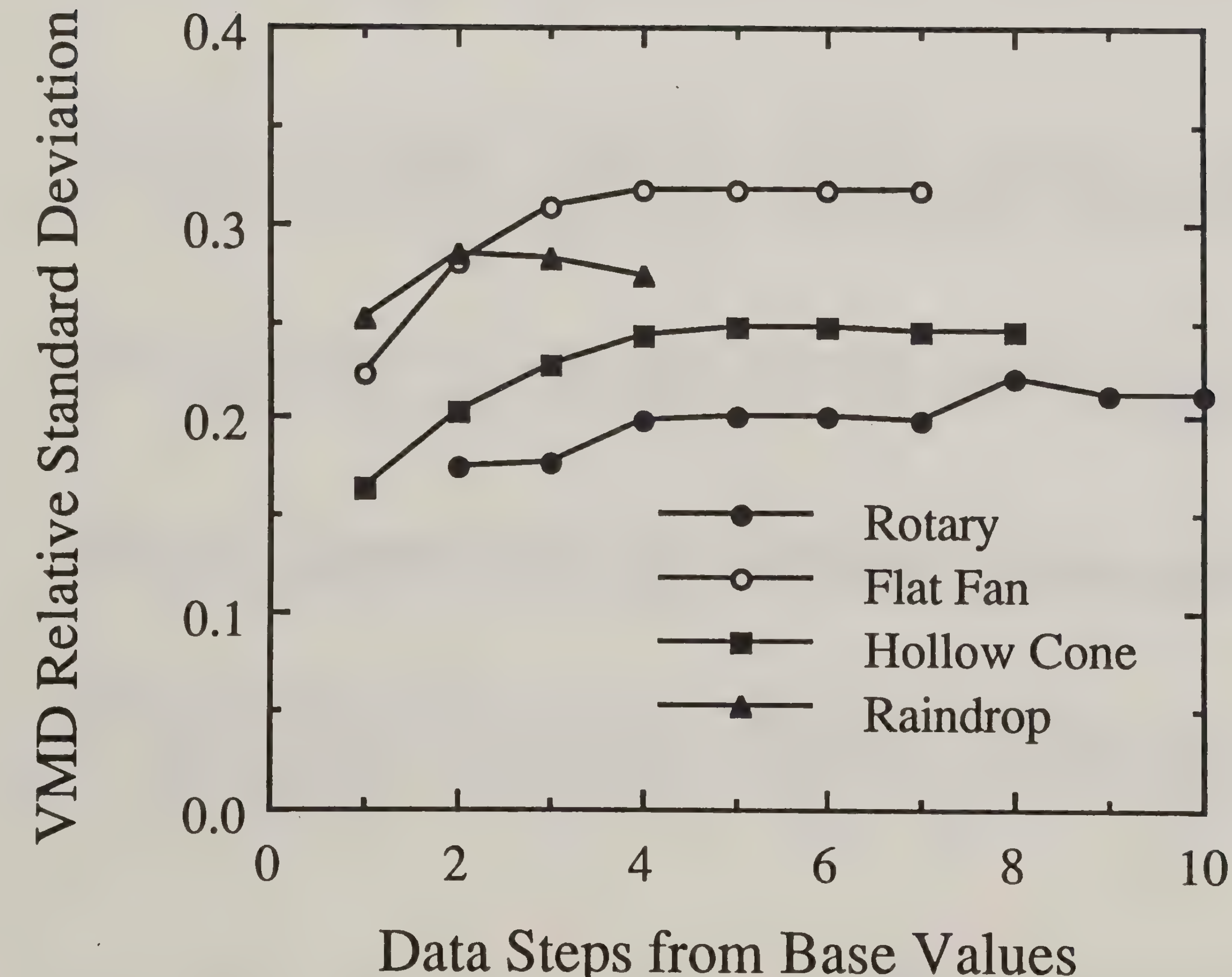

Figure 9. Accuracy of the Taylor series - influence coefficient approach for VMD applicable to a subset of the drop size distribution data base.

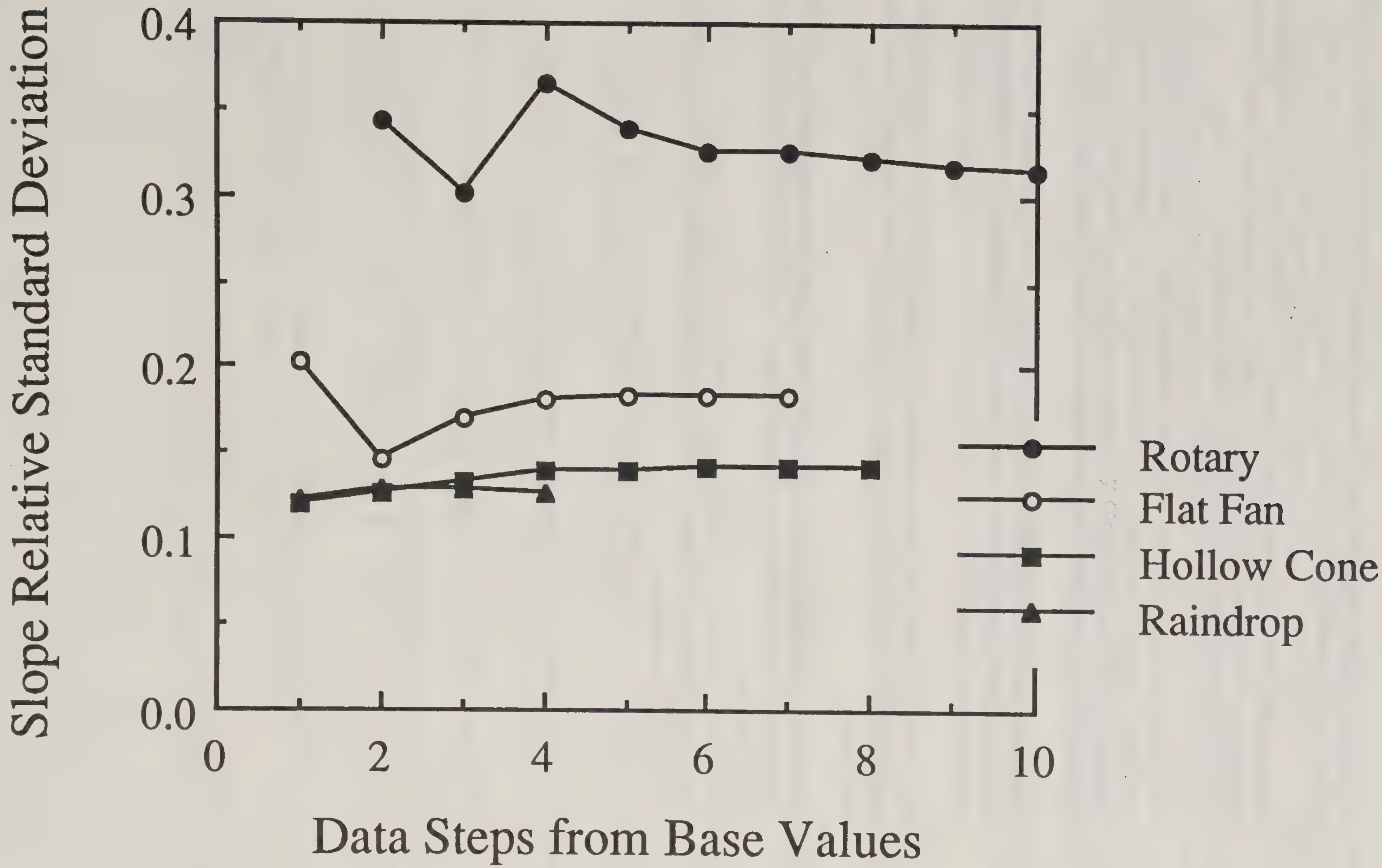

Figure 10. Accuracy of the Taylor series - influence coefficient approach for Slope applicable to a subset of the drop size distribution data base.

Conclusions and Recommendations

An examination of the USDA Forest Service spray drop size distribution data base indicates the following:

1. Through the normal probability approach we have identified a consistent technique with which to reduce the drop size distribution data base to manageable pairs of coefficients for VMD and Slope.

2. We have shown by Taylor series expansion that the variability across the data base does not permit much more than 20 to 30 percent accuracy in predicting VMD and Slope. This is probably not good enough for field applications. A forthcoming sensitivity study will examine this effect.

3. Nonetheless, the reduction technique enables the user to restructure any drop size distribution to any detail desired; this approach is presently being implemented into FSCBG.

4. More sophisticated approaches, such as neural network logic, should be explored in an attempt to improve the prediction capability of this technique.

5. It would appear that wind tunnel tests bracketing field expectations will be sufficient to interpolate with this technique and recover accurate drop size distributions.

6. The interpolation scheme should be implemented into an expanded DROPSIZE program.

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